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Incremental Improvement of Dichotic Left Ear Accuracy and Toe Gnosis Between 9 and 10 Years of Age: Implications for Maturation of a Portion of the Corpus Callosum and of the Sense of Self

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Analyses of the data from 212 boys and girls, aged 7–14 years, demonstrated a relatively abrupt and permanent decrease in the numbers of errors for dichotic (left ear) word listening and for toe gnosis after the ninth year. This pattern was not observed for right ear errors, finger gnosis, or indices of finger and foot agility. The results are compatible with the hypothesis that the final differentiation of the paracentral lobules and adjacent corpus callosum by the most distal portions of the Anterior Cerebral Artery occurs around 9 or 10 years of age. Implications for the development of the sense of self, enhanced apprehension, and ''the sense of a presence'' are discussed.

INTRODUCTION

We have assumed that if structure dictates function, then microstructure should determine microfunction. For the last decade the Laurentian University Neuroscience Research Group (Healey, Persinger, & Koren, 1996; Persinger, 1993; Persinger & Makarec, 1991, 1992; Richards & Persinger, 1994; Tiller & Persinger, 1994) has been pursuing the neurocognitive correlates for the experience of ''the self''. The phenomenological experiences of the self, whose

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components include the constructs of self-concept and self-esteem (Persinger, 1993), have been hypothesised to be strongly correlated with linguistic processes (Edelman, 1989; Jaynes, 1976; MacLean, 1990) that are associated with the microstructure that is usually more evident within the left cerebral hemisphere than within the right hemisphere.

Considering the propensity for most functions to exhibit some compensatory activity or homologous representation within the opposite hemisphere, we reasoned that the equivalent of the left hemispheric sense of self should be generated by right hemispheric processes. During left hemispheric dominance, such as the normal waking, conscious state, the right hemispheric equivalents of the sense of self would not be represented within or subject to ''awareness''. Our interpretation of interhemispheric axonal organisation suggests that the intrusion of information concerning the right hemispheric equivalence of the sense of self into left hemispheric awareness is prohibited by intracallosal recurrent collaterals.

However, when the intrusions occur the person experiences the right hemispheric equivalent of the left hemispheric sense of self as ''a presence''. This sense of a presence is described as a perception of an actual entity (or ''Being'') or sometimes as a process ''watching'' the experiencer. We suspect this common experience of a sensed presence has emerged in human cognition because of the mild discrepancies between the neurocodes for information processed in each hemisphere. Because the sense of self and ordinary awareness are primarily involved with left hemispheric processes, information coded within right hemispheric formats could be experienced but would be discriminable as non-self or ''ego-alien''. These phenomena have been persistently reported in the history of human experience (Evans, 1984).

If the sense of self is primarily a left hemispheric process and the sense of a presence is associated with the awareness of the intrusiveness of the right hemispheric equivalent to the sense of self, then there should be clear neurocognitive correlates during ontogeny within the age range of 9 to 10 years. The expected asymmetry in hemispheric maturation has been documented by Thatcher, Walker, and Giudice (1987). They found that electroencephalographic activity of frontal-occipital pairs over the left hemisphere achieved 90% of adult values by about 5 years of age, whereas the homologous pairs over the right hemisphere did not achieve these values until about 9 years of age. Shortly thereafter (about age 12 years) the development of the corpus callosum approaches an asymptote (Hayakawa et al., 1989).

This particular interval (9–10 years) is also the transition period between middle and late childhood and has been associated with the emergence of different phenomenological experiences of the sense of self. There is more emphasis on the affective (emotional) dimensions of language and the impact concerning death becomes more acute or meaningful (Rando, 1984). Our clinical observations, from referrals of both normal children and those whose

families requested counselling or assistance, indicate that children who are 9 to 10 years of age begin to report more experiences of ''foreboding presence'' or apprehension when they are alone or in quiet places (basements, bedrooms) at night. The experiences are often attributed to culturally congruent sources (horror characters, demons).

Our hypothesis was simple. If normal maturation of the corpus callosum is required in order to increase the probability of awareness for the right hemispheric equivalents of the left hemispheric sense of self, then there would be a concurrence of maturation for two tasks whose integrity requires the medial surfaces of the hemispheres within the region of that portion (ventral to and including the paracentral lobule) of the corpus callosum that mediates information between the temporoparietal lobes (Musiek, 1986). Consequently we predicted an incremental maturation within this region as defined by an ontogenically abrupt decrease in the numbers of dichotic listening errors for the left ear and an increase in proficiency of accuracy for toe gnosis.

METHOD

To test this hypothesis we re-examined the data collected for children (7 years to 14 years of age) to whom either the Roberts' Dichotic Word (60 pairs) Listening Test (Roberts et al., 1994) or Toe and Finger Gnosis Tasks (Richards & Persinger, 1992) had been given. The procedures for the toe gnosis are similar to those routinely employed to discern a child's accuracy for recognising which finger is lightly touched, except that the procedure is applied to the toes. The child is asked, with his or her eyes closed and the foot blocked from view, to identify which toe has been lightly touched.

In order to minimise selection artifacts, all of the subjects from the two studies (n = 244) were employed even though the cell sizes were unequal (range 12–29 subjects per age per experiment). All children were monolingual (English) and were scholastically average students according to the teachers' criteria; the numbers of boys and girls per age interval were approximately equal. As references and as controls for non-specificity, measurements of foot agility, finger agility, and finger gnosis were also recorded (Persinger & Richards, 1995).

RESULTS

A statistically significant age difference was evident for the numbers of dichotic word listening errors for the left ear [$F = 9.05$, $P < .001$]. Post hoc analyses (Tukey's, $P < .05$) indicated that the mean numbers of errors for the left ear for the 7–9-year-olds were between 12.7 through 13.7 (average SD = 6.5) but then significantly decreased to between 5.0 and 7.0 for ages 10–14 years ($\eta = 0.54$).

Similarly, the (total for both feet) numbers of errors for toe gnosis exhibited statistically significant ($P < .001$) age-dependent differences ($\eta = 0.49$).

To directly compare the relative reduction in errors for toe gnosis and the left ear during dichotic word listening as a function of age, z scores were calculated for each of the two scores (each population of subjects) separately. These results are shown in Fig. 1. A three-way analysis of variance for these z-scores was then completed as a function of age (7–14 years), test (toe gnosis errors vs left ear errors), and sex (boys vs girls). There were no statistically significant main effects or interactions (all Fs < 1.50) except for differences between the ages [$F(7,212) = 10.72$, $P < .001$; $\eta = 0.50$].

Post hoc analyses indicated that the z scores for errors for toe gnosis and left ear accuracy for the 7-and 8-year-olds were significantly higher than those for the 10-, 11-, 12-, 13-, and 14-year olds who did not differ significantly from each other. The nine-year-olds' scores were significantly more inaccurate than the 12- and 13-year-olds' scores. As shown in Fig. 1, the relatively sudden and statistically significant decrease in error rate (one indicator of maturation) occurred for both the left ear accuracy and the recognition of the toes between the ages of 8 and 10 years.

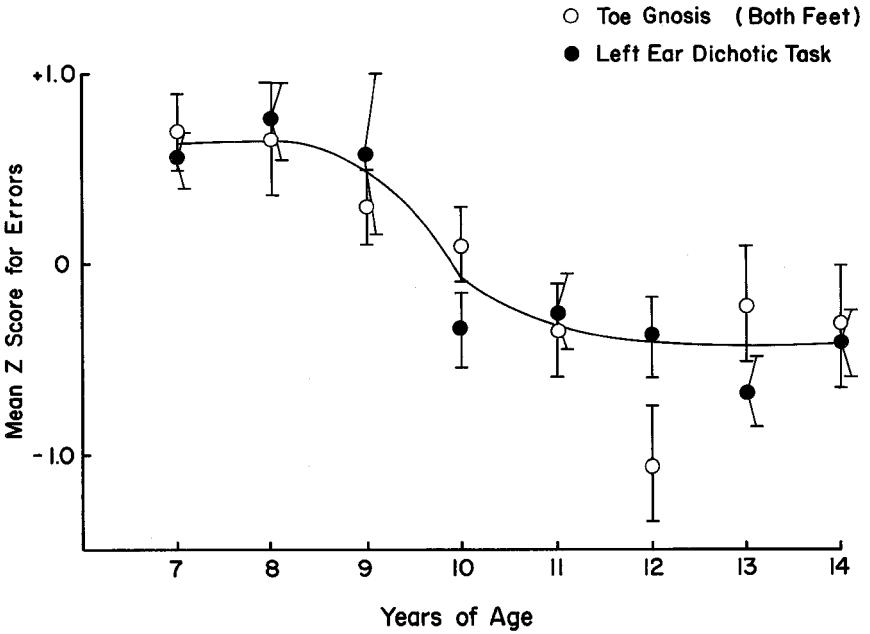

FIG. 1. Mean z scores for total numbers of errors for toe gnosis and left ear dichotic listening errors as a function of age. Vertical bars indicate standard errors of the means. The solid line indicates best-fit curve.

The number of errors during dichotic listening for the right ear did not exhibit statistically significant age differences [$F(7,152) = 1.90$, $P > .05$]; the mean and standard deviations were 8.2 and 4.9, respectively. There was also no significant change in the total numbers for errors of finger gnosis over this age span [$F(7,77) = 2.17$, $0.05 < P < .10$]; the mean and SD for errors for both hands were 2.0 and 2.4, respectively. Direct comparisons of the z-scores for the numbers of errors for the right ear and for the fingers from both hands (combined) are shown in Fig. 2.

Ontogenetic changes in measures that have been employed to infer function of the frontal lobes did not exhibit a sudden, incremental change. The means and standard deviations (in parentheses) for the numbers of (index) finger taps per 10 seconds (mean for both hands) for the eight age groups were 29 (4), 33 (3), 38 (3), 42 (5), 44 (5), 46 (3), 45 (4), and 49 (5), respectively [$F = 29.89$, $P < .001$]. The values for foot taps (mean for both feet) per 10 seconds were: 23 (3), 28 (4), 30 (7), 33 (5), 35 (6), 36 (7), 41 (5), and 43 (5), respectively [$F = 14.85$, $P < .001$].

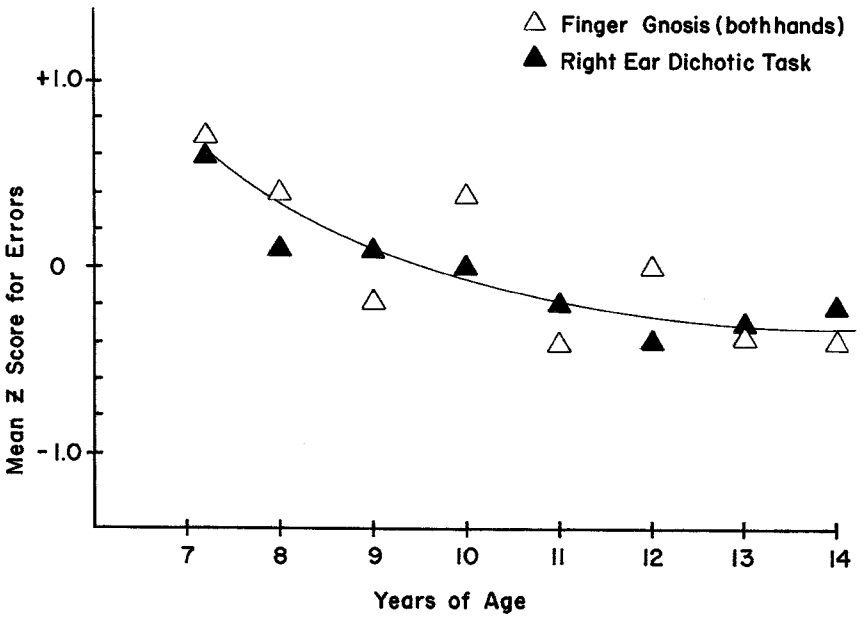

FIG. 2. Mean z scores for the total numbers of errors for finger gnosis and words presented to the right ear during dichotic word listening as a function of age. The solid line indicates best-fit curve. Standard errors of the mean were between .2 and .3.

DISCUSSION

The results of this cross-sectional study indicated that the development (as inferred by decreased errors) of the ability to recognise individual fingers, without the benefit of visual or proprioceptive feedback, and words presented to the right ear during dichotic listening did not change appreciably between 8 and 14 years of age. On the other hand the development of the ability to recognise individual toes, without the benefit of visual or proprioceptive feedback, and words presented to the left ear during dichotic listening displayed a relatively abrupt increase in proficiency after 9 to 10 years of age.

The absence of a significant interaction between the gnosis errors for toes of both feet, dichotic errors for the left ear, and age indicates that the age-dependent alteration in proficiency for these tasks exhibited a similar ontogenic pattern. If left ear proficiency is primarily associated with corpus callosal capacity (Musiek, 1986) and toe recognition is associated with neuronal maturation of the portion of the (parietal) paracentral lobule that is dorsal and proximal to auditory corpus callosal fibres, than the quantitatively similar development suggests a single source of variance.

The most parsimonious explanation would involve delayed maturation of the most distal branches of the Anterior Cerebral Artery (Carpenter & Sutin, 1983). Both the paracentral lobules of the medial surface of the parietal lobes (where the sensation for the lower limbs and toes is represented), and the intracallosal connections for the superior temporal gyri, are supplied by these distal branches. A vascular hypothesis would imply that the normal delay in callosal development is associated with the maturation of secondary capillarisation. It would be required to maintain the level of glial metabolism that would be essential for the integrity of the myelin within intracallosal and interhemispheric axonal pathways. In this context, the relatively sudden improvement of left ear accuracy during dichotic listening because of an incremental maturation of this particular section of the corpus callosum would be associated with improved toe gnosis simply because of the proximity and shared vascularity between the paracentral lobules and the subadjacent callosum.

That concordance between changes in the error rate for the left ear during dichotic listening and bilateral toe gnosis was not an artifact of general maturation is indicated by the absence of these age-dependent changes for finger gnosis. A non-specific auditory difficulty is not likely in light of the absence of the non-linear change for the error rate in right ear listening for the same dichotic task. Although both finger agility and foot agility exhibited age-dependent changes, they were linear and did not display the same ontogenetic pattern. If (foot and finger) agility is an index of neuronal maturation then the results suggest that the frontal lobes continue to develop, without an analogous incremental change, throughout this age span in children.

Maturational changes in behaviours are a function of the ontogenetic changes in metabolic activity within specific cerebral regions (Chugani & Phelps, 1986). The transition between middle and late childhood is associated with the emergence of qualitative cognitive properties that are important to the emergence of the sense of self. Several researchers (Edelman, 1989; Jaynes, 1976; MacLean, 1990) have argued that the experiences of (adult) self, awareness, and identity are secondary to the development of microstructural (synaptic) changes that also result in the emergence of linguistic functions primarily (and normally) within the left hemisphere (Corina, Vaid, & Bellugi, 1992).

We (Persinger, 1993; Persinger & Makarec, 1992) have hypothesised that the very common occurrence of a ''presence'' or entity during twilight states of consciousness is due to transient interhemispheric intrusions of the right hemispheric *homologue* of the sense of self into left hemispheric awareness. Although these phasic episodes would be triggered by limbic activity (Persinger, 1994), the phenomenological experience of the ''presence'' would require the type of hemispheric intercalation that is provided by the corpus callosum. Our hypothesis has been supported experimentally. Cook and Persinger (1997) have induced the sensed presence by applying weak, complex magnetic fields that simulate brain activity first over the right temporoparietal region and then equally and simultaneously across this region for both hemispheres (which we hypothesised should enhance the intercalation).

Because both overt behaviours and subjective experiences are determined by those portions of the brain that are most metabolically active, the details of the ''presence'' should reflect the properties of the right (primarily temporoparietal) cortical regions. Consequently the subjective spatial location of the presence could be along the experiencer's left side and would be associated with enhanced vigilance, anxiety, or sudden apprehension. Commensurate with this model is the observation (Persinger & Makarec, 1991) that the affective component of self concept, i.e. self-esteem, is lower for adults who should experience more frequent intercalations as inferred by psychometric inferences of right hemispheric cognitive style.

Greater intrusion of right hemispheric processes through a more mature corpus callosum into the extremely egocentric (Leahy, 1985), left hemispheric cognition of the normal 9–10-year-old child would be important for self-identity (Pikunas, 1976), emotional identification with peers of the same sex, and perception of social (primarily based on spatial) relationships (Lynch, 1981). The sudden increase in the probability of intrusions of right hemispheric (Persinger, 1993) properties (such as anxious vigilance) into left hemispheric, linguistic processes at approximately 9 to 10 years of age might also explain the enhancement of insecurity, and feelings of inadequacy and anxiety which emerge at this time in some children (Pikunas, 1976). Children with above average numbers of intrusions and poor linguistic definitions of the self would

be expected to report more frequent sensed presences and apprehension when alone or in a quiet place. These children would not be able to articulate the cause of the anxiety because these intrusive experiences would not have been associated with appropriate verbal labels and images.

Within clinical contexts great care would be required, because inappropriate labels or explanations for these experiences, supplied by the therapist, could lead to erroneous attributions of their causes. Once the verbal labels have been reinforced by their consequences, primarily reduction in anxiety, the child would begin to experience these post hoc experiences and images during the intrusions. The intensity and apparent ''reality'' of these label-evoked images would also be enhanced by the recursive reduction in anxiety, facilitated during each session, that is associated with their discussion and revivification (Persinger, 1992).

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